Gender differences in Occupant Posture during Driving and Riding

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Hattie C. Cutcliffe, Jóna M. Ólafsdóttir, Jonas Östh, Johan Davidsson, Karin Brolin

Abstract The aim of this study was to compare postures of male and female vehicle occupants, tested in both front seat positions, during normal driving and deceleration onset. These data are useful for the development and initialisation of computational human body models. A secondary aim was to examine the effect of reversible, motorised seat belts in these events.

Kinematics were analysed for volunteers driving on rural roads, prior to autonomous braking (11 m/s^2 deceleration). Two restraint configurations were tested: a standard versus a motorized belt, activated 200 ms before braking initiation. Kinematic metric comparison via ANCOVA was performed to understand postural differences across gender, role (driver/passenger), and belt type (standard/motorised). Data was analysed prior to and at vehicle deceleration, termed typical riding and initial braking, respectively.

While males and females displayed similar postures during typical riding, differences existed between drivers and passengers, especially with respect to neck posture. Drivers displayed more protracted neck postures, with significantly smaller (by 22-27 mm, depending on gender) head-to-sternum horizontal distances, than passengers.

Motorised belts significantly changed posture during initial braking, notably of the chest (which was shifted posteriorly by approximately 13 mm, depending on gender and role), while standard belts did not. Within a given belt type, occupants' change in posture was similar across gender and role during initial braking.

Keywords Braking, Driver and passenger, Gender, Kinematics, Reversible motorised seat belt

I. INTRODUCTION

Motor vehicle accidents are a global concern, with an estimated 1.24 million deaths and 20–50 million non-fatal injuries occurring annually worldwide [1]. While current safety systems have substantially increased occupant protection, future fatalities and morbidities can be reduced through ongoing safety system development. For example, vehicle safety technology is moving from passive restraint systems, exhibiting fixed functionalities, to adaptive systems that adjust output depending on speed and static occupant and vehicle parameters [2,3]. As occupant position can be used by adaptive systems, understanding typical occupant positions and how they may change pre-crash is crucial for optimisation and evaluation of these systems. Increasingly, computational human body models (HBMs) are used in vehicle safety system assessment. It is important, therefore, that HBMs are as biofidelic as possible, in areas such as initial position, muscle activation, and gender.

Previous computational work investigating occupant posture has illustrated that initial position influences a HBM's outcome and overall injury risk prediction [2,4-6]. Likewise, several driving simulator studies and observations of real driving have categorised typical occupant positions [3,7-11], demonstrating that occupants display a variety of positions that diverge from HBM posture in safety simulations.

Additionally, occupant gender is important to consider in HBMs, as differences exist between male and female position and response in vehicles. As the risk for whiplash injuries – neck injuries with low initial severity but high risk of long-term impairment – is greater for females than males [12,13], several studies have examined kinematic differences across gender. In forward whiplash-like perturbation studies, female peak kinematic responses were larger than male responses [14]. In low-speed rear-impact tests and rear-impact sled tests, females demonstrated larger peak head and T1 forward horizontal accelerations than males [15,16], with lower and earlier peak rearward head and T1 horizontal displacements [16,17]. In frontal sled tests, females

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exhibited larger peak kinematics than males [18,19]. During braking, females displayed larger peak forward displacements and longer peak displacement durations than males of the same size [20]. Additionally, females sit closer to the steering wheel than males [7,9], with smaller head-to-head restraint gaps [9]. Females have also been shown to exhibit less lordosis in the cervical spine in seated occupant postures than males [21]. As each of these factors may influence whiplash injury risk, these findings illustrate the importance of quantifying kinematics separately for both genders.

The aim of this study was to determine and compare typical posture of male and female occupants while driving and riding for two belt conditions – standard and motorized – and to define biofidelic initial conditions for HBMs. Typical postures were quantified and are provided for these conditions.

II. METHODS

This study analysed data from a volunteer study involving a total of 20 volunteers (11 male, nine female), which was approved by the Ethical Review Board at the University of Gothenburg, Sweden. Volunteers were informed about the testing and provided their written consent prior to testing. Volunteers were tested in two roles: first as drivers [22], and then as passengers [23]. They were subjected to 29 (20 driver, nine passenger) 11 m/s^2 braking interventions. The interventions were conducted on rural roads and in a passenger car in which two seat-belt retractor configurations were used in a randomised order: a standard one, locking at 4 m/s^2 vehicle deceleration or a belt pay out acceleration of 15 m/s^2 (subsequently denoted "standard"); and a reversible one with an electrical motor providing 170 N of reversible belt pretension force and an approximate maximum retraction speed of 300 mm/s (subsequently denoted "motorized"). Each braking intervention was triggered without any prior notification to the volunteer. Vehicle deceleration occurred on average 350 ms after triggering; for trials with the motorised belt, pretension was activated 200 ms before deceleration (Fig. 1). Prior to the braking interventions, volunteers' anthropometry was measured in the laboratory (Table A1, see Appendix). Sitting height was the distance in the mid-sagittal plane between the seated surface and the superior aspect of the head [24], with volunteers seated on a stool.

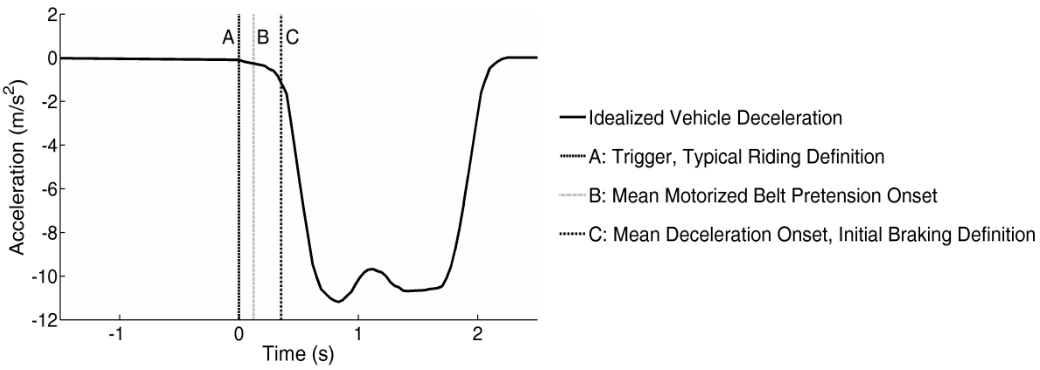

Fig. 1. Schematic of typical vehicle deceleration, demonstrating time points of interest in this study.

Two different time periods were analysed: termed "typical riding" and "initial braking" (A and C in Fig. 1, respectively). Eighteen braking interventions per volunteer were analysed (12 driver, six passenger). The volunteers were able to partially adjust the driver seat and steering wheel to find a comfortable driving position and were told to keep their hands symmetrically on the steering wheel. Allowed adjustments were: translation of the seat, change of the inclination angle of the seat back, and steering wheel position and angle. In agreement with the Euro NCAP frontal impact test protocol [25], the passenger seat was fixed (in the mid fore/aft position, with a seat-back angle of 22° according to the manufacturer's specification), and volunteers were instructed to keep their feet symmetrical to the midline of the footwell and to rest their hands on their lap.

Kinematic data were acquired at 50 Hz through film analysis (TEMA Automotive, Image Systems, Linköping, Sweden). Posture was measured with video tracking of markers on the volunteer's head and chest (Fig. 2a). In the present study, the head centre of gravity (CG) position is used, and was calculated [22] from the film markers close to the ear and eye (Fig. 2a). Kinematic posture data are presented in a vehicle fixed coordinate system, with positive X being forward and positive Z being upward (Fig. 2b). Head rotation was defined as the angle between the horizontal plane and the Frankfort plane, with positive rotation representing extension.

Relative head-to-sternum distance was defined as the difference between the calculated head CG and the chest marker, effectively measuring the posture of the neck: an individual with a larger head-to-sternum X in one position compared to another would have a more retracted posture in the former; likewise, an elevated head-to-sternum Z would indicate a more erect neck posture. Head-to-head restraint distance was the difference between the head CG and the mid-point on the anterior surface of the head restraint, in the mid-sagittal plane. For typical riding, head rotation in the sagittal plane, head-to-head restraint X, head-to-sternum X, and head-to-sternum Z were analysed and defined as the average value over the first 100 ms after trigger (Fig. 1, A). For each, the median across all trials of a given condition was used to represent each volunteer's typical riding response. For initial braking, the postural metrics were defined at deceleration onset (Fig. 1, C). Prior to deceleration, activation of the motorised belt pretension caused translation of the chest marker in Z. Therefore, head CG X and Z displacement, sternum X displacement, changes in head rotation, head-to-head restraint X, and head-to-sternum X are presented for initial braking. For each trial, the volunteer's change in metric was taken as the difference between the response at the initial braking and typical riding time points. The median change across all trials of a given condition was used to represent each volunteer's response.

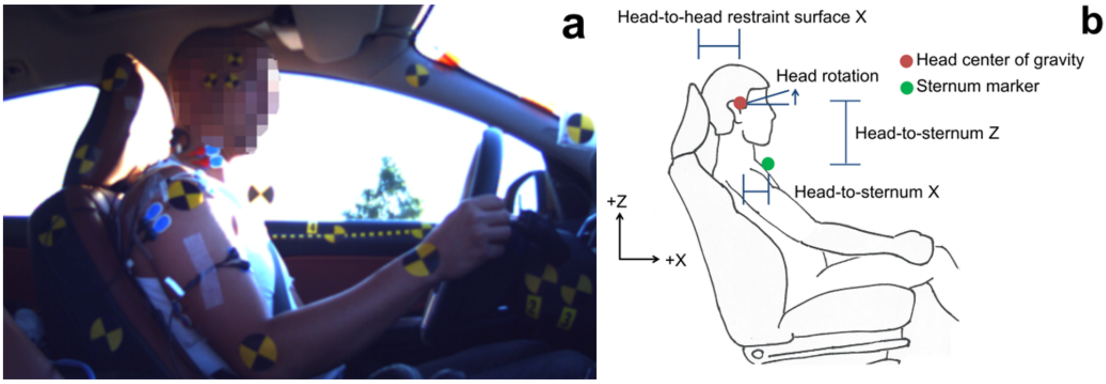

Fig. 2. Kinematic marker locations and postural metrics used in this study: a. view of vehicle interior and volunteer, showing film marker placement, for video analysis (adapted from [22], by permission of The Stapp Association); b. schematic of postural metrics used in this study.

Statistical analysis included an assessment of normality and homoscedasticity and a general test for group differences via a repeated-measures ANCOVA, including sitting height as a covariate. A 5% significance level was used. For typical riding, two-way repeated measures designs were used, with the two factors being role (driver or passenger) and gender, and with role as the repeated measure. For initial braking, three-way repeated measures designs were used, the additional factor being belt type (motorised or not), which was also a repeated measure. Data processing was carried out in MATLAB (Version 8.0.0, MathWorks, Natick, MA), while statistical analyses were performed in SAS (Version 9.3, SAS Institute Inc., Cary, NC).

III. RESULTS

The sitting height of the 20 volunteers was normally distributed, with a mean of 923 mm (males: 947 mm, females: 894 mm), standard deviation of 39 mm (males: 26 mm, females: 33 mm), and range of 132 mm (males: 81 mm, females: 95 mm). A post-hoc t-test of the sitting heights indicated that the male and female sitting height was significantly different ($p < 0.05$), with females being shorter than males (Table A1).

Typical Riding

Figure 3 illustrates the typical riding postural metrics while the data (mean, standard deviation) are given in Table I. Role and gender had significant main effects on the head-to-sternum X and head-to-sternum Z, but neither had a statistically significant effect on the head-to-head restraint X. Volunteers showed between 22 and 27 mm (depending on gender) larger mean head-to-sternum X distances as passengers than as drivers, indicating more retracted neck postures as passengers. Additionally, males showed significantly larger mean distances than females (between 5 mm and 10 mm, depending on role), meaning males exhibited more retracted postures than females. Conversely, volunteers' mean head-to-sternum Z distances were 14 mm and 2 mm larger as drivers than as passengers, while males showed between 6 mm and 18 mm larger mean head-to-sternum Z distances than females. Role also had a significant main effect on head rotation, though the difference between groups was small (less than 6°) and driven by the males: female drivers and passengers had mean head rotation angles of 5° and 6°, while male drivers showed smaller head rotations (4°) than male passengers (10°). Sitting height showed significant covariance with head-to-head restraint X, head-to-sternum X, and head-to-sternum Z (Fig. 3).

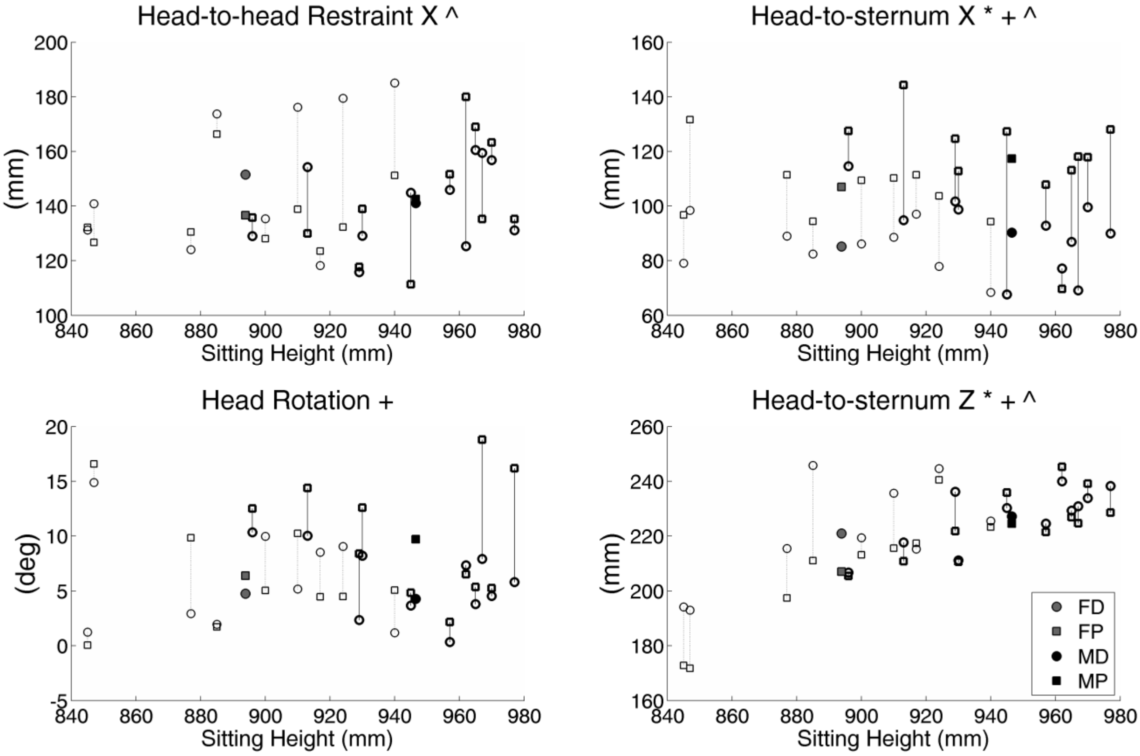

Fig. 3. Postural metrics per volunteer (open markers) during typical riding, as a function of sitting height. Mean postural metrics (solid markers) are plotted at the mean male and mean female sitting height. Thick marker outlines depict males, while thin marker outlines depict females. All head metrics are defined at the head centre of gravity. * = Significant main effect of gender, + = significant main effect of role, ^ = significant covariance with sitting height. (F = female, M = male, D = driver, P = passenger.)

TABLE I

MEAN VALUE (STANDARD DEVIATION) OF POSTURAL METRICS IN TYPICAL RIDING

	Head Rotation (°) +	**Head-to-head Restraint X Distance (mm) ^**	**Head-to-sternum X Distance (mm) *+^**	**Head-to-sternum Z Distance (mm) *+^**
Female Drivers	5 (6)	152 (27)	85 (10)	221 (19)
Female Passengers	6 (5)	137 (14)	107 (12)	207 (23)
Male Drivers	4 (5)	141 (16)	90 (14)	227 (11)
Male Passengers	10 (5)	143 (21)	117 (19)	225 (12)

Initial Braking

Figure 4 illustrates the change in metrics from typical riding to initial braking after motorised belt pretension onset, while the data (mean, standard deviation) are given in Table A2 (see Appendix) for both motorised and standard belts. Though role had a significant main effect for several metrics, the mean differences between roles were small. For instance, role significantly affected the head CG X and Z displacement, but the mean displacement varied less than 6 mm and 3 mm across groups, respectively. Similarly, role had a significant main effect on the change in head-to-head restraint X, where the difference in mean values between groups was less than 9 mm. Main effects of role were not found for the other metrics.

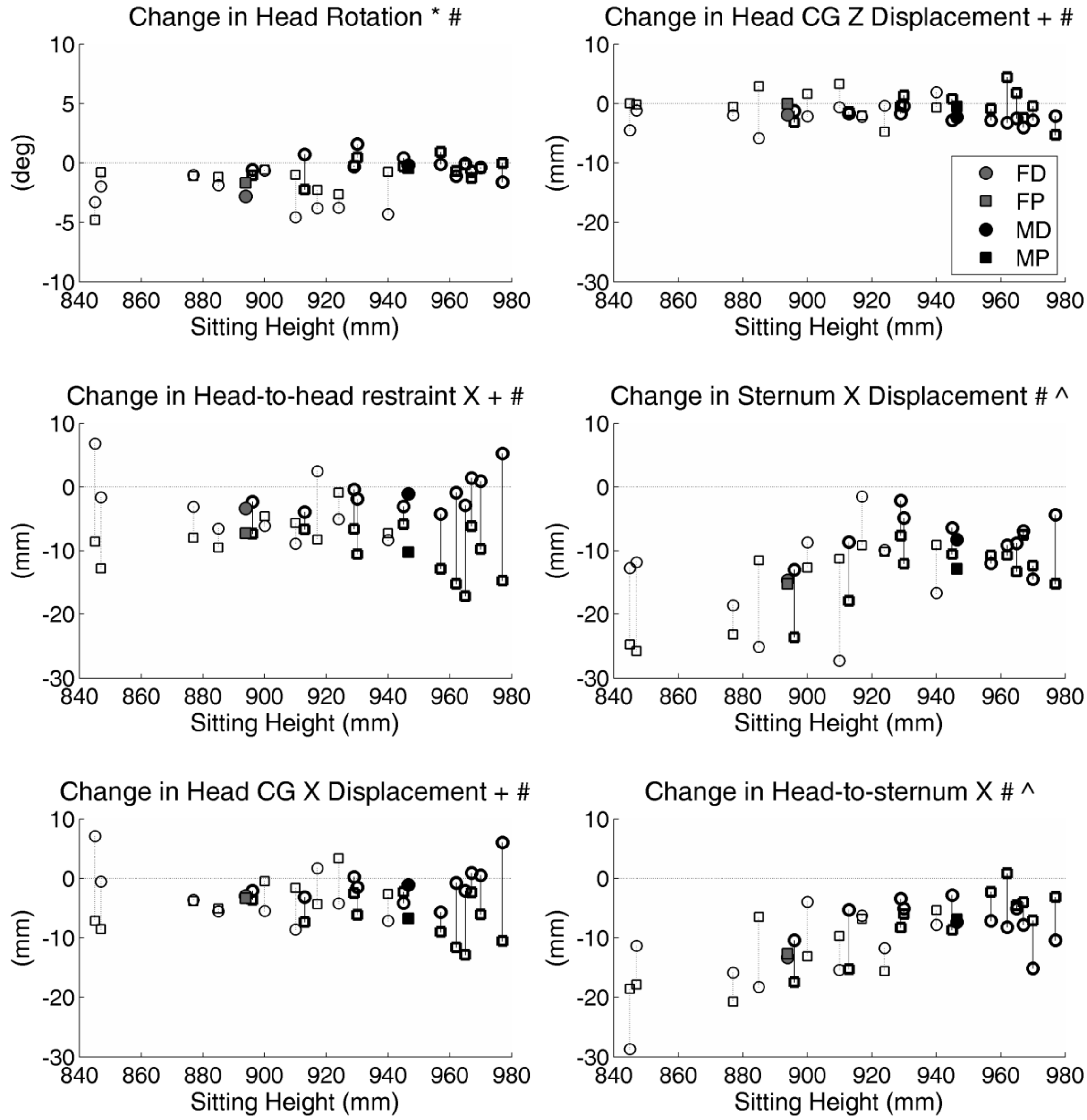

Fig. 4. Change in postural metrics per volunteer (open markers) with motorised belts, as a function of sitting height. Mean changes in postural metrics (solid markers) are plotted at the mean male and mean female sitting height. Thick marker outlines depict males, while thin marker outlines depict females. All head metrics are defined at the head centre of gravity. * = Significant main effect of gender, + = significant main effect of role, # = significant main effect of belt type, ^ = significant covariance with sitting height. (F = female, M = male, D = driver, P = passenger.)

No significant main effects of gender were found for any metric, except for the change in head rotation, where the largest mean change was 3° for female drivers with motorised belts. However, most groups showed no change in head rotation. Sitting height showed significant covariance with sternum X displacement and the change in head-to-sternum X.

Compared to standard belts, motorised belts were found to significantly affect all metrics. Notably, the mean sternal X location was shifted posteriorly by approximately 13 mm (depending on gender and role) with motorised belts. Correspondingly, the mean head-to-sternum X distance was reduced by 13 mm for females and by 7 mm for males, indicating that neck posture became more protracted relative to the typical riding posture. The changes in postural metrics seen with standard belts during initial braking were smaller than the standard deviations exhibited during typical riding, for all comparable metrics, indicating that there were no other factors except the belt influencing the occupant response.

IV. DISCUSSION

The influence of gender on posture for volunteers riding in a passenger car was analysed for volunteers tested both as drivers and as passengers, based on experiments previously reported [22,23]. Across gender, occupants displayed generally similar postures during typical riding, while more differences in posture were present across role. These differences may influence, for example, the whiplash injury risk and are important to model with HBMs when evaluating restraint systems computationally. At initial braking, significant differences in the change in posture were seen with motorised belts compared with standard belts, but occupants' change in posture was generally similar across gender and role within a given belt type.

Limitations

As different-sized volunteers could be expected to have different postural metrics [26], one limitation is the significant gender difference in sitting height of approximately 50 mm. This may influence Z values, but is not likely to affect X values. Another limitation was the definition of head-to-head restraint distance, which was the distance between the head restraint surface and the head CG, as opposed to the back of the head as is typically used. The lack of a headband or other marking device made the more common definition unavailable. However, this does not affect the conclusions drawn.

There are limitations inherent due to the experimental procedure, such as the use of a specific test vehicle or the level of autonomous deceleration applied. With respect to the current investigation, all braking events analysed were autonomous events, and volunteers were unaware of the timing of an impending deceleration. Because each volunteer underwent multiple deceleration events, they may have been aware that future decelerations would occur but did not know when the decelerations would take place. Additionally, as the passenger seat was fixed during this investigation, the typical riding posture for passengers does not take into account gender differences in seat adjustment. However, it is plausible that passengers adjust the seats to a lesser extent than drivers during real driving. On the other hand, the driver data capture differences in seat adjustment and are more representative of real life driving postures.

Furthermore, our kinematic measurements are not without limitation. The driver and passenger data were collected using different cameras, positioned on different sides of the vehicle. This necessitated that markers be placed on both sides of the head. Thus, sources of error include marker placement and video tracking. As these errors are random, their expected value is zero; likewise, multiple trials of each condition helped mitigate the effects of error in video tracking. However, there is also error in camera calibration. These errors were small, as assessment of accumulated errors in film analysis indicated length distortions of no larger than 7% and 9% for the driver and passenger data, respectively, for any marker [22,23].

Lastly, while the sample size (20 volunteers) may be limited, it is similar to that of other human volunteer studies [15-19,21,27-30]. These data are valuable and provide insight into the variation in response between males and females. However, these data may not accurately capture the posture and response of older adult subjects, as the volunteers in this study were relatively young: mean male age: 33 years; mean female age: 29 years; range: 23-68 years (Table A1, see Appendix). Therefore, further studies should be performed to quantify the effects of age on posture and response to motorized belts.

Typical Occupant Posture

For typical riding, male and female posture was generally similar, while larger differences were present across role. Although head-to-sternum X and head-to-sternum Z were significantly affected by gender, with females displaying smaller values than males, this may be the result of smaller anthropometry as sitting height was a significant covariate for both metrics. Alternatively, it may reflect differences in cervical posture between males and females. Through seated MRI investigations, Sato *et al*. [21] reported less cervical lordosis and less thoracic kyphosis in females than males when sitting in a rigid seat similar to those used in rear-impact sled tests. The larger head-to-sternum X distances of males relative to females during typical riding observed in this study may, then, be a reflection of the increased cervical lordosis that males are reported to exhibit [21]. However, both of these neck postural metrics were also significantly affected by role. Volunteers displayed significantly smaller (by over 20 mm, Table I) head-to-sternum X values as drivers than as passengers, meaning that drivers adopted a more protracted head posture than passengers. Likewise, volunteers displayed significantly larger head-to-sternum Z values as drivers than as passengers; yet this difference was large for females (14 mm), but small for males (2 mm) (Table I). As whiplash injury risk differs across occupant role [31], further research is warranted to investigate whether different initial neck postures influence whiplash injury risk. Although the magnitude of these differences in initial posture may be small (relative to peak displacements observed during a braking event or crash), coupled with different muscle activation states they could have implications for whiplash injury risk. Indeed, differences in male and female muscle response during later stages of the braking events analysed in this study have been reported [22,23]. Finally, as the allowable seat adjustments were different between roles, it is possible that this may have influenced the results. However, there is little research on voluntary passenger posture and seat adjustment preference.

In the current study, gender did not significantly affect the mean head-to-head restraint X distance. Yet, female drivers displayed 11 mm larger mean head-to-head restraint X values than male drivers, while female passengers exhibited 6 mm smaller values than male passengers (Table I). While one study [7] similarly found no difference across gender, other studies observed smaller head-to-head restraint distances in females than in males [9,15,16]. However, this metric may be influenced by head size or other anthropometric variables, as indicated by the significant covariance with sitting height. Though also not significantly different across role, female volunteers demonstrated 15 mm larger distances to the head restraint as drivers than as passengers, while male drivers and passengers exhibited similar distances (141 mm and 143 mm, respectively). This indicates that perhaps driving tasks influence the distance to the head restraint, via an interaction between role and gender. Even if differences in whiplash injury risk are due to other factors than the distance between the head and head restraint, this difference may influence injury risk. It promotes additional research on drivers and passengers separately, and on the sensitivity of whiplash injury risk to differences in initial occupant position. Further studies are needed to investigate this issue as the head-to-head restraint horizontal distance may also be influenced by the seat pan inclination (which was not adjusted in this experiment), instruction to hold both hands on the wheel, or the relatively few subjects analysed.

Several studies present head and neck initial positions. For instance, initial head and torso positions of volunteers in braking tests in vehicles on the road are reported [20]. Our results (Table I) are in line with their mean head-to-sternum X and Z values of approximately 82 mm and 196 mm, respectively. In sled tests with volunteers seated in the front passenger seat of a 1991 Honda Accord, initial positions of the head and torso are presented [32,33]. However, head position was defined at the glabella, while torso position was measured at the manubrium. Thus, the initial head-to-sternum X values in these studies are smaller than those reported here, as the glabella is more anterior than the head CG. Likewise, several sled tests present initial positions of head and spinal markers, but not of chest or sternum markers [18,19,27,28,34]. Therefore, the valuable initial position data detailed in these studies are not directly comparable to the results presented here.

On the other hand, several studies report initial head rotation angles. This study found mean initial head rotation angles of 4–10°. Though lower than previously reported values, these angles are still similar given the variation in reported values. Several forward sled tests report mean initial head rotation angles of 7°–12° for subjects unaware of the timing of impending perturbations [14,32,33], while others report mean initial head angular positions of 25°–27° [29,30]. These differences may be due to different experimental set-ups, such as between sled tests and actual driving and riding tasks. As the volunteers in the current study were not instructed on how to position their head or direct their gaze, the head positions adopted in this study are likely relevant postures that provide adequate vision commensurate to the role (either driver or passenger). It can be noted that some sled tests [32,33] are within one standard deviation of the head rotation angles presented here (males: -1°–15°; females: -1°–11°), while others [14,29,30] generally result in larger head rotation angles.

Initial Braking and Effect of Motorised Seat Belts

The mean initial braking response with standard belts illustrated only a small change (generally less than 1 mm, Table A2) in posture from typical riding values, consistent with prior 0.8 g and 1.0 g frontal sled tests [18,19,27,28] showing no significant motion during the first 100 ms after deceleration. Hence, the change in posture compared to typical riding seen with motorised belts can be considered an effect of the motorised belts themselves, and not of deceleration onset. This is supported by the analyses of standard belts in initial braking, where any reported changes are smaller than the standard deviation of typical riding values (i.e. not distinguishable from typical riding) for comparable metrics.

Motorised belts significantly altered all postural metrics compared with standard belts. Though the mean changes seen with motorised belts were small for metrics associated with the head, they were slightly larger in metrics associated with the sternum. Indeed, the sternum moved approximately 13 mm posteriorly with the motorised belts (depending on gender and role), while there was almost no motion with standard belts. These differences were present throughout the braking event: occupants with motorised belts displayed significantly less forward displacement than occupants with standard belts [22,23]. Similarly, median peak forward chest and neck displacements of volunteers were found to be 42% and 34% less, respectively, in braking tests with reversible belt tension compared to tests without [35]. The larger changes in sternum marker position coupled with smaller changes in head marker position induced an effective protraction of the neck during initial braking (indicated by reduced head-to-sternum X distances). The head-to-sternum X distance for females (in both roles) was reduced by 13 mm, while for males (in both roles) it was reduced 7 mm relative to the posture at typical riding. Though the difference in the effective protraction induced by motorised belts between males and females is relatively small (5 mm), it highlights the need to measure kinematics separately for both genders.

V. CONCLUSIONS

For use in HBM initialisation, postures of male and female occupants were quantified while driving on rural roads, in driver and front passenger seats using both standard and reversible motorised seat belts. The typical riding posture of males and females were found to be generally similar. Though not significantly different, female drivers held their heads farther from the head restraint than male drivers. Moreover, drivers and passengers exhibited significantly different neck postures (quantified via head CG location with respect to the chest), motivating further studies investigating occupant position during real driving, to better characterise occupants in positions such as the rear seat. Compared to standard belts, motorised belts significantly changed occupant posture during initial braking, especially with respect to the chest. Changes in occupant response with motorised belts were generally similar across role and gender.

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VIII. APPENDIX

TABLE A1
VOLUNTEER ANTHROPOMETRIC DATA
SD = STANDARD DEVIATION

	Age (Years)	Height (cm)	Weight (kg)	Sitting Height (mm)
Male 1	27	184	78	977
Male 2	26	173	79	930
Male 3	26	175	82	967
Male 4	38	184	85	945
Male 5	68	184	81	965
Male 6	29	169	75	896
Male 7	28	183	75	962
Male 8	36	176	85	913
Male 9	30	180	72	970
Male 10	23	177	68	929
Male 11	29	175	72	957
Male Mean (SD)	32.7 (12.5)	178.2 (5.2)	77.5 (5.6)	946.5 (26.2)
Female 1	28	173	72	940
Female 2	44	160	60	847
Female 3	29	168	60	900
Female 4	27	158.5	56	845
Female 5	27	163.5	58	877
Female 6	28	166	60	910
Female 7	27	168	58	885
Female 8	24	171	53	917
Female 9	25	171	58	924
Female Mean (SD)	28.8 (5.9)	166.6 (5.0)	59.4 (5.2)	893.9 (33.2)

TABLE A2
MEAN CHANGE (STANDARD DEVIATION) IN POSTURAL
METRICS FROM TYPICAL RIDING TO INITIAL BRAKING

	Head Rotation (°) *#	Head CG X (mm) +#	Head CG Z (mm) +#	Head-to-head Restraint X Dist. (mm) +#	Sternum X (mm) #^	Head-to-sternum X Dist. (mm) #^
			Motorised Belt			
Female Drivers	-3 (1)	-3 (5)	-2 (2)	-3 (5)	-15 (8)	-13 (7)
Female Passengers	-2 (1)	-3 (4)	0 (2)	-7 (3)	-15 (7)	-13 (6)
Male Drivers	0 (1)	-1 (3)	-3 (1)	-1 (3)	-8 (4)	-7 (4)
Male Passengers	0 (1)	-7 (4)	-1 (3)	-10 (4)	-13 (5)	-7 (5)
			Standard Belt			
Female Drivers	0 (1)	0 (3)	0 (1)	-1 (3)	1 (1)	0 (3)
Female Passengers	0 (1)	0 (3)	0 (3)	-5 (3)	0 (1)	0 (3)
Male Drivers	0 (1)	1 (2)	0 (1)	-1 (2)	0 (0)	0 (2)
Male Passengers	0 (0)	0 (2)	1 (2)	-5 (3)	0 (1)	0 (3)

* = Significant main effect of gender, + = significant main effect of role, # = significant main effect of belt type, ^ = significant covariance with sitting height.